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Modulation and Control of Multilevel Inverter Fed DTC Induction Motor Drive

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(Abstract) In this paper, a new switching table for Direct Torque Control (DTC) of a nine-level Multi Point Clamped (MPC) Voltage Source Inverter (VSI) fed induction motor drive is proposed. A Nine level inverter has 729 switching states and there are 217 effective vectors are possible. The proposed multi level inverter drive scheme is capable for enough degrees of freedom to control both electromagnetic torque and stator flux with very low ripple and high dynamic speed response. From the simulation results shows that feeding electrical drive with multi level inverter can greatly improves the drive performance. The performance of this control method has been demonstrated by simulations performed using a versatile simulation package, Matlab/Simulink.

Keywords: DTC; nine-level MPC VSI; Switching table; Induction motor; Matlab/Simulink.

1. INTRODUCTION

Multilevel power conversion technology is a very rapid growing area of power electronics with good potential for further development. The most attractive application of this technology are in the medium to high voltage range (2-13kv), and include induction motor drives, power distribution,power quality and power conditioning applications [1],[2],[3],[4] .In general multilevel power converters can be viewed as voltage synthesizers, in which the high output voltage is synthesized from many discrete small voltage levels. The main advantages of this approach is,The voltage capacity of the existing devices can be increased many times without the complications of static and dynamic voltage sharing that occurring series connected device. It is possible to obtain refind voltage wave forms and reduced Total Harmonic Distortion (THD) in voltage with increased number of voltage levels. It is possible to reduce the electromagnetic interference problem by reducing the switching dv/dt stress. Multilevel wave forms naturally limit the problems of large voltage transients that occur due to the reflections on cables, which can damage the motor windings and cause other problems [5].Multilevel inverters can produce an output voltage wave form having a large number of steps with low harmonic distortion. They can also reduce the stress on the switching devices as source with lower levels. These features have made them suitable for application in large and medium induction motor drives.

A multilevel system that is capable of realizing a SVPWM waveform ranging from 2-level to 5-level is described in[9], In MPC VSI fed inverter system is so called since in their architecture there are several points clamped to specific voltages using some components. Even diode-clamped converters belong to this family because the bus between two switches is clamped by a clamping diode. Furthermore, when the number of voltage level is odd, the converters are called Neutral Point Clamped (NPC) because the neutral point is clamped, has found wide application in medium-voltage high-power applications [6].The main features of the MPC converter include reduced dv/dt and THD in its AC output voltages in comparison to the conventional two level converters. The inverter scheme proposed in this paper produces 729 switching states and there are106 effective space vectors are possible in this system. This results in a reduction of the switching ripple in the motor electromagnetic torque waveform.

In principle, DTC method is based on instantaneous space vector theory. By optimal selection of the space voltage vectors in each sampling period, DTC achieves effective control of the electromagnetic torque and the stator flux on the basis of the errors between theirs references and estimated values. It is possible to directly control the inverter states through a switching table, in order to reduce the torque and flux errors within the desired bands limits [8].The present work is based on the study of the application of DTC to the nine-level MPC VSI, and the advantages that can be obtained from using this topology when compared to the seven-level and five-level inverter.

This paper is organized as follows: the multilevel DTC scheme is discussed in section 2 and operating principal of MPC is discussed in section 3.In the sections 4 application of DTC to multilevel MPC is presented, and the Matlab design of case study and simulation results of the proposed method are exposed in section 5.Finally conclusions are given in the

last section.

2. DTC PRINCIPAL

Fig.1 shows a simple structure of the conventional DTC for Induction motor drive. In DTC the reference to be applied is directly calculated from the equation of the load, usually an Induction Motor (IM). In the following, a short description of DTC is presented, just to introduce to its extension to multilevel VSI. Considering Park transform of IM equations, it is possible to write in equation (1), where φ_s is the stator flux, u_s, i_s and r_s are the stator voltage, current and resistance respectively.

$$\frac{d\overline{\varphi_s}}{dt} = \overline{u_s} - r_s \overline{i_s} \qquad (1)$$

Ignoring the contribution of the current, which can be considered small in the respect of the stator voltage, the variation of stator flux can be ascribed all to the voltage applied. So, a proportional relationship between flux variation and voltage in a given cycle T_c can be found by discretizing (1) as shown fig.2.

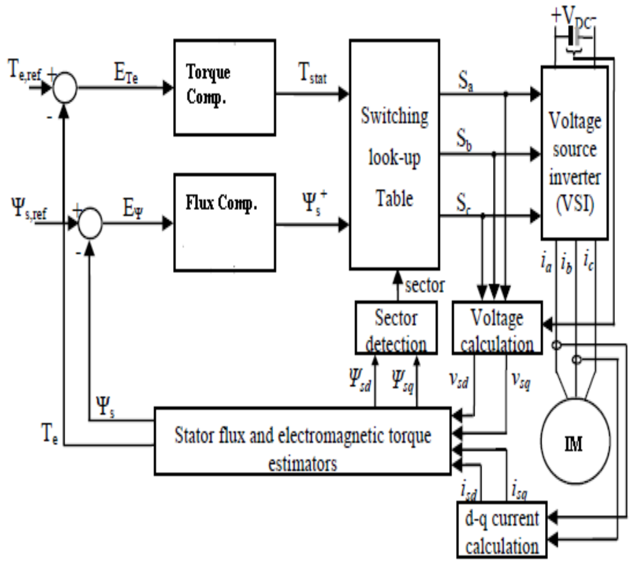

Fig.1.The conventional DTC scheme of IM drive

Analyzing the equation binding the stator and rotor fluxes (φ_s and φ_r) to the torque (T_e), it is possible to find that an augmentation of the angle between fluxes (v_{sr}) means an augmentation of torque, as (3) shows, where M, σ, Ls and p are the mutual inductance, the leakage inductance and number of poles respectively.

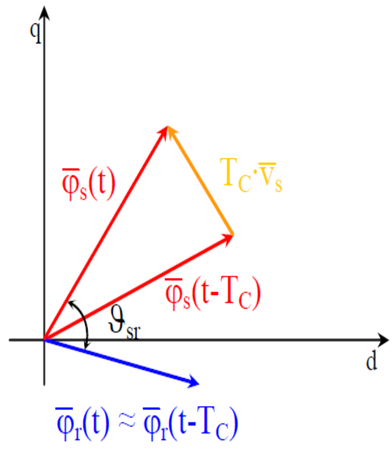

Fig.2. DTC Principles: vector representation of the stator an rotor fluxes during a sample interval T_c.

$$\Delta\overline{\varphi_s} \cong T_c \overline{u_s} \qquad (2)$$

$$T_e = \frac{3}{2}\frac{p}{2}\frac{M}{(\sigma L_s)^2}\varphi_s \varphi_r Sin(v_{sr}) \qquad (3)$$

The relationship between stator and rotor fluxes it can be assumed that a fast variation of the stator flux angular speed will reflect in an increment of the angle v_{sr} as Fig.2. Schematically shows. So, imposing a particular stator voltage, it is possible to control either the stator flux amplitude or the torque. The vector $\Delta\varphi_s \cong T_c u_s$ can be decomposed in the component parallel and perpendicular to the stator flux; the parallel component modifies the stator flux amplitude while the perpendicular component controls the torque

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3. OPERATING PRINCIPAL OF MULTI POINT CLAMPED

Multi Point Clamped (MPC) is so called since in their architecture there are several points clamped to specific voltages using some components. Even diode-clamped converters belong to this family because the bus between two switches is clamped by a clamping diode. Furthermore, when the number of voltage level is odd, the converters are called Neutral Point Clamped (NPC) because the neutral point is

clamped. As Fig.3 shows, the 5-level leg is completely different: in MPCs the voltages are clamped using couples switch-diode instead of using a simple diode. Anyway, given a number of levels, the number of switches needed by MPC is the same needed by diode-clamped. The control of MPC leg is more complicated in the respect of other topologies. Even this kind of converter allows finding complementary couples of switches.The constrain so introduced is not physiologically necessary, but it is a simple way to simplify the control scheme and the switching table (Table I).

Table I. Switching States of A Five-Level Inverter

Switches state								
T_1	T_2	T_3	T_4	T_1'	T_2'	T_3'	T_4'	V_{AO}
0	0	0	1	1	1	0	0	$-2U_0$
0	0	0	1	1	1	0	1	$-U_0$
0	0	1	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	1	0	U_0
1	1	1	0	0	0	0	0	$2U_0$

Furthermore, to avoid shortcut, T_3 and T_4 must be complementary controlled. The same must happens for T'_3 and T'_4. Table 1is a possible switching table for a 5-level MPC leg; there is an intra-phase redundancy only for the middle level. Anyway, it is better to have T_4 turned on in order to limit the reverse voltage drop uponT_2.Dependently on the switching table used, the maximum reverse voltage drop over the components changes and a preliminary analysis must be done to choose the suitable component. Moreover, the switches in the middle of the leg must carry twice the voltage of the others.

4. APPLICATION OF DTC TO MULTI LEVEL MPC VSI

4.1. Five level MPC VSI Fed DTC IM Drive.

The DTC algorithm can even be applied to multilevel VSI exploiting more than the eight vectors available in standard DTC.Lots of algorithms have been proposed to extend DTC concept to multilevel converters [9],[10]. The differences among the algorithms concern several aspects of the system, like the voltage selection schemes, the exploitation of the topology implemented, the control regulators, etc.

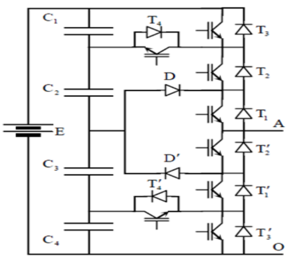


Fig.3. 5-level Multi Point Clamped leg

In Fig.4 (a) all the possible vectors generable by a 5-level converter are depicted as the vertices of the triangular grid. In particular the position of the stator flux is assumed to be given by the vector $\overline{\varphi}_s$ which is lying in the highlighted hexagon. The control strategy must choose among the vectors nearest to flux the one which cancels torque and flux errors. These vectors are drawn in red in Fig.4 (b) and they were given a name: $\overline{V}_1, \overline{V}_2, \overline{V}_3, \overline{V}_4, \overline{V}_5$ and $\overline{V}_6$. Accordingly to standard DTC technique, the vector minimizing torque contribution (i.e. $\overline{V}_2$ and $\overline{V}_5$) are not used. The other four vectors can be used exploiting their properties above torque and flux. The vector $\overline{V}_1$ is used to increase the flux and to decrease the torque; applying $\overline{V}_3$ both flux and torque increase; $\overline{V}_4$ has opposite effects than $\overline{V}_1$ and $\overline{V}_6$ is used when both flux and torque have to be decreased.

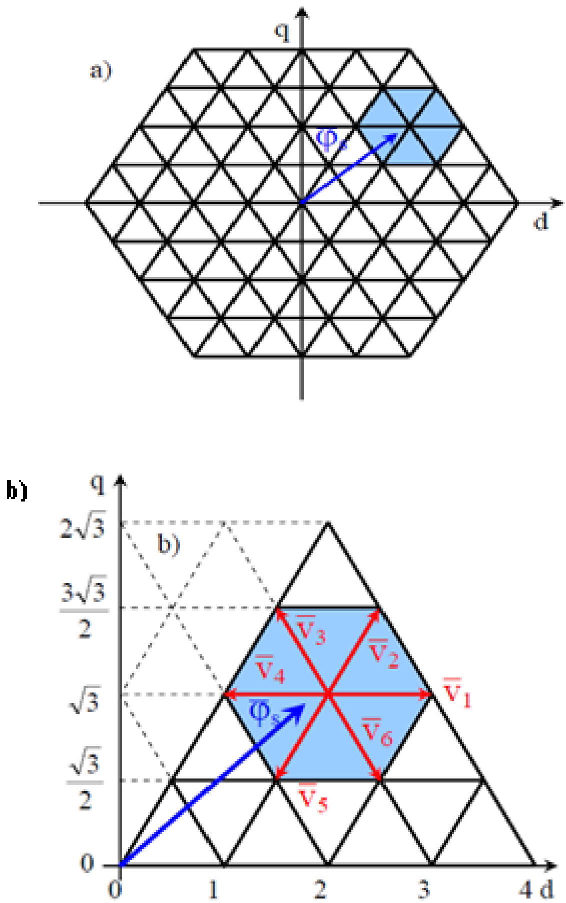


Fig.4.Multilevel DTC. a) Vectors generated by a 5-level converter and reference; b) Zoom of the area near to the reference and the six vectors which can be applied.

Fig.5. shows the schematic diagram of MPC five-level VSI. Each phase consists of six switches, each one with its freewheeling diode in series and two other in parallel and two clamping diodes that allow the connection of the phases

outputs to the middle point O. Table 1 illustrates the switching states of this inverter for one phase. Since five kinds of switching states exist in each phase, a five-level inverter has 125 switching states and there are 61 effective vectors are possible. According to the magnitude of the voltage vectors, We divide them into nine (9) groups (V_0),(V_1,V_2,V_3,V_4,V_5,V_6),(V_{44},V_{45},V_{46},V_{47},V_{48},V_{49}),(V_{26},V_{27}, V_{28},V_{29},V_{30},V_{31}),(V_{75},V_{76},V_{77},V_{78},V_{79},V_{80},V_{81},V_{82},V_{83},V_{84},V_{85}, V_{86}),(V_{63},V_{64},V_{65},V_{66},V_{67},V_{68}),(V_{118},V_{119},V_{120}, V_{121},V_{122},V_{123}),(V_{106},V_{107},V_{108},V_{109},V_{110},V_{111},V_{112},V_{113},V_{114},V_{115},V_{116},V_{117}),(V_{100},V_{101},V_{102},V103,V_{104},V105)

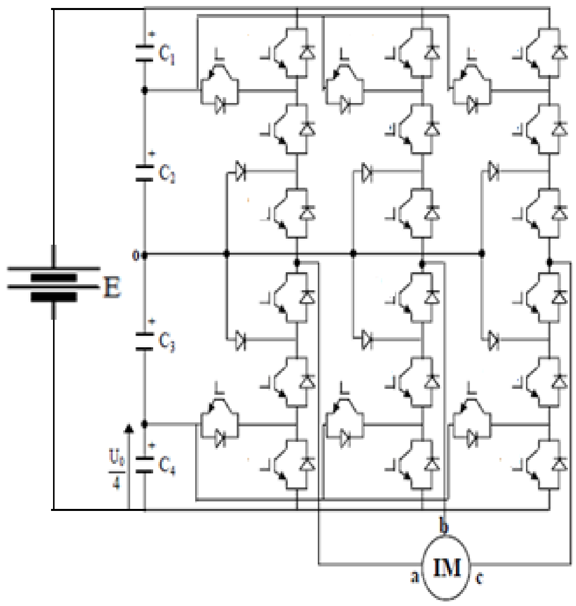
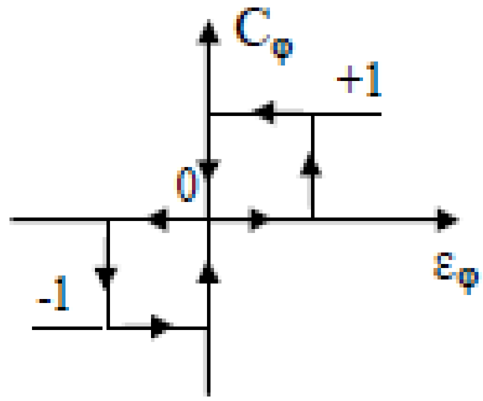
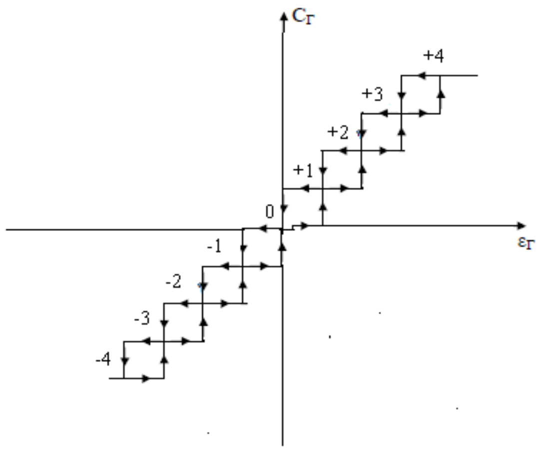


Fig.5. Schematic diagram of a five-level MPC VSI

The flux control is made by classical two-level hysteresis controller, so a high level performance torque control is required, and the torque is controlled by an hysteresis controller built with four lower bounds and four upper known bounds. A combination of the controller's outputs and the sector is then applied to a new optimal switching table (Table II) which will give the appropriate voltage vector to reduce the number of commutation and the level of steady state ripple. The hysteresis blocks are designed as it is shown in fig.6.



a)Flux Comparator



b)Torque Comparator

Fig.6.Flux and Torque Hysteresis blocks

Using the hysteresis comparator outputs flux C_F and torque C_T and the stator flux sector S, the proper output vector can be chosen to correct the error due to the relation in the switching table. The switching configuration is made step by step. The selection of a voltage vector at each cycle period Te is carried in order to maintain the flux and torque within the limits of two hysteresis bands. Several switching tables for three-level inverter are presented in [10]. Also, a new switching table for the inverter selector has been developed in Table II, to achieve an accurate control. In order to simplify, the mechanical rotor speed will be considered when assigning the voltage vectors needed at each one of those sectors. The speed of the stator flux linkage vector is given by the modulus of the applied voltage vector. Thus, the voltage vectors will be chosen according to the rotor speed [8]. Voltage vectors with low amplitude will be chosen for lower speeds.

Table II Switching Table

$C\varphi$	C_T	Switching states											
		1	2	3	4	5	6	7	8	9	10	11	12
+1	+4	107	101	109	102	111	103	110	104	115	105	117	100
	+3	76	64	78	65	80	66	82	67	84	68	86	63
	+2	118	27	119	28	120	29	121	30	122	31	123	26
	+1	44	2	45	3	46	4	47	5	48	6	49	1
	0	Zero Vector											
	-1	49	1	44	2	45	3	46	4	47	5	48	6
	-2	123	26	118	27	119	28	120	29	121	30	122	31
	-3	68	85	63	75	64	77	65	79	66	81	67	83
	-4	105	116	100	106	101	108	102	110	103	112	104	114
-1	+4	102	110	103	112	104	114	105	116	100	106	101	108
	+3	65	79	66	81	67	83	68	85	63	75	64	77
	+2	28	120	29	121	30	122	31	123	26	118	27	119
	+1	3	46	4	47	5	48	6	49	1	44	2	45
	0	Zero Vector											
	-1	5	48	6	49	1	44	2	15	3	16	4	47
	-2	30	122	31	123	26	118	27	119	28	120	29	121
	-3	67	83	68	85	63	75	64	77	65	79	66	81
	-4	104	114	105	116	100	106	101	108	102	110	103	112
0	+4	109	102	111	103	113	104	115	105	117	100	107	101
	+3	78	65	80	66	82	67	84	68	86	63	76	64
	+2	119	28	120	29	121	30	122	31	123	26	118	27
	+1	45	3	46	4	47	5	48	6	49	1	44	2
	0	Zero Vector											
	-1	48	6	49	1	44	2	45	3	46	4	47	5
	-2	122	31	123	26	118	27	119	28	120	29	121	30
	-3	67	83	68	85	63	75	64	77	65	79	66	81
	-4	104	114	105	116	100	106	101	108	102	110	103	112

4.2 Seven – level MPC VSI Fed DTC IM Drive

In Seven level MPC VSI each phase consists of eight switches, each one with its freewheeling diode in series and two other in parallel and two clamping diodes that allow the connection of the phases outputs to the middle point O. Table III illustrates the switching states of this inverter for one phase.

Since seven kinds of switching states exist in each phase, a seven-level inverter has 343 switching states and there are 79 effective vectors. According to the magnitude of the voltage vectors, we divide them into nine (9) groups:
$[V_0]$,$[V_1,V_2,V_3,V_4,V_5,V_6]$,$[V_{44},V_{45},V_{46},V_{47},V_{48},V_{49}]$, $[V_{63},V_{64},V_{65},V_{66},V_{67},V_{68}]$,$[V_{75},V_{77},V_{79},V_{81},V_{83},V_{85}]$, $[V_{100},V_{101},V_{102},V_{103},V_{104},V_{105},V_{106},V_{108},V_{110},V_{112},V_{113},V_{114},V_{115},V_{116},V_{117},V_{118},V_{125}]$,$[V_{205}, V_{206},V_{207},V_{208},V_{209},V_{210}]$, $[V_{218},V_{219},V_{220},V_{221},V_{222},V_{223},V_{224},V_{225},V_{226},V_{228},V_{230},V_{232},V_{234},V_{236},V_{237}]$, $[V_{296},V_{297},V_{298},V_{299},V_{300},V_{301},V_{302},V_{303},V_{304},V_{305},V_{306},V_{308},V_{310},V_{312},V_{314},V_{316}]$.

A combination of the controller's outputs and the sector is then applied to a new optimal switching table (Table IV) which will give the appropriate voltage vector to reduce the number of commutation and the level of steady state ripple.

Table III Switching States of A Seven-Level Inverter

T_1	T_2	T_3	T_4	T_5	T_1'	T_2'	T_3'	T_4'	T_5^1	V
1	0	0	1	0	0	0	0	0	0	$-3U_0$
0	1	1	1	0	0	0	0	0	0	$-2U_0$
0	0	1	1	0	0	0	1	0	0	$-U_0$
0	0	0	0	1	1	0	0	1	1	0
0	0	1	0	0	0	0	1	0	0	0
0	0	0	0	1	1	1	0	0	0	U_0
0	0	1	1	1	1	0	0	0	0	$2U_0$
0	0	0	0	1	1	1	0	0	0	$3U_0$

4.3 Nine – level MPC VSI fed DTC IM Drive

In nine level MPC VSI each phase consists of ten switches, each one with its freewheeling diode in series and two other in parallel and two clamping diodes that allow the connection of the phases outputs to the middle point O. Table V illustrates the switching states of this inverter for one phase.

Table V Switching States of A Nine-Level Inverter

T_1	T_2	T_3	T_4	T_5	T_6	T_1'	T_2'	T_3'	T_4'	T_5'	T_6'	V
1	0	0	0	0	0	1	0	0	0	0	0	$-4U_0$
0	1	1	1	0	1	1	0	0	0	0	0	$-3U_O$
0	0	1	0	0	1	1	1	0	0	1	0	$-2U_0$
0	0	1	0	0	1	0	0	1	1	1	1	$-U_0$
0	0	0	1	1	1	1	0	0	0	0	0	0
1	1	1	0	0	0	1	1	0	0	0	1	0
0	1	1	1	1	1	0	0	1	0	0	0	U_0
0	1	1	0	1	1	1	0	0	0	0	0	$2U_0$
0	0	1	1	1	1	0	0	1	1	0	0	$3U_0$
1	1	0	0	1	1	1	0	0	0	0	0	$4U_0$

Since nine kinds of switching states exist in each phase, a nine-level inverter has 729 switching states and there are 106 effective vectors. According to the magnitude of the voltage vectors, we divide them into thirteen (13) groups:
$[V_0]$, $[V_1, V_2, V_3, V_4, V_5, V_6]$,$[V_{44}, V_{45}, V_{46}, V_{47}, V_{48}, V_{49}]$,$[V_{123}, V_{124}, V_{125}, V_{126}, V_{127}, V_{128}]$, $[V_{135}, V_{137}, V_{139},V_{141},V_{143}, V_{145}]$,$[V_{180},V_{181},V_{182},V_{183},V_{184},V_{185},V_{186},V_{188},V_{190},V_{192},V_{194},V_{196}]$,$[V_{250},V_{251},V_{252},V_{253},V_{254},V_{255},V_{256},V_{258},V_{260},V_{262},V_{264},V_{266}]$,$[V_{303},V_{304},V_{305},V_{306}, V_{307},V_{308}]$,$[V_{395}, V_{396}, V_{397}, V_{398}, V_{399}, V_{400}]$,$[V_{488},V_{489},V_{490},V_{491},V_{492},V_{493},V_{494},V_{495},V_{496},V_{498},V_{500},V_{502},V_{504},V_{506}]$,$[V_{588},V_{589},V_{590},V_{591},V_{592},V_{593},V_{594},V_{595},V_{596},V_{598},V_{600}, V_{602}, V_{604},V_{606}]$,$[V_{676},V_{677},V_{678},V_{679},V_{680},V_{681},V_{682},V_{683},V_{684},V_{685},V_{686}]$,$[V_{686}, V_{688}, V_{690}, V_{692}, V_{694}, V_{696}]$.

The flux control is made by classical two-level hysteresis controller, so a high level performance torque control is required, and the torque is controlled by an hysteresis controller built with eight lower bounds and eight upper known bounds.

A combination of the controller's outputs and the sector is then applied to a new optimal switching table (Table VI) which will give the appropriate voltage vector to reduce the number of commutation and the level of steady state ripple.

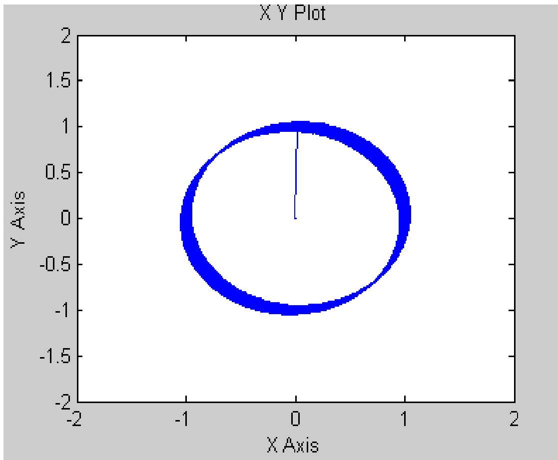
5. MATLAB DESIGN OF CAUSE STUDY AND SIMULATION RESULTS

The multilevel DTC strategy has been tested by simulations are shown in fig.7. The induction motor parameters are as follows:Rs=4.85Ω, Rr=3.805Ω, Ls=274mH, Lr=274mH, Lm=258mH, p=2, J=31g.m2, V=220V,power=1.5kW and speed=1420rpm. All simulations have a sample time for the control loop of 100μs, the voltage of the DC bus is 514V. The requested space voltage vector, demanded by the DTC strategy, is assured as shown by the line voltage in Fig.14 Thus, if compared with a three-level DTC strategy [9], the dv/dt applied to the motor terminals is greatly reduced. Furthermore, the electromagnetic torque is also improved. It is possible to reduce pulsation amplitude by approximately a factor of 2 when compared to a seven - level DTC strategy.

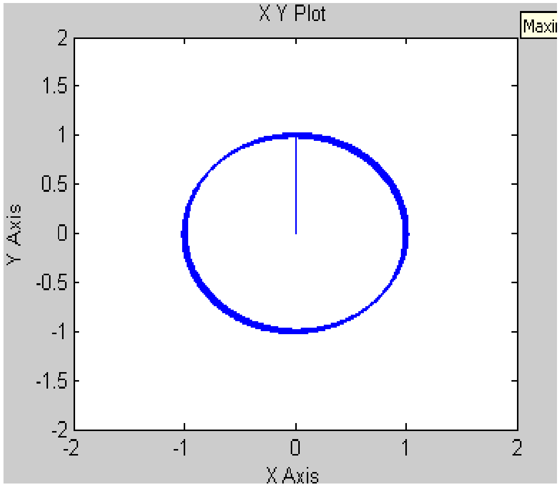
To show the effectiveness of the DTC with 5-level,7-level and 9-level inverters with SVPWM switching technique a simulation work has been carried out on induction motor.

Fig.10. shows the Flux Trajectories of five, seven and nine level inverters fed DTC Induction motor drive. From the simulation results flux trajectories is a circle and answers more quickly in nine- level as compared to five, seven level inverter fed DTC induction motor drive.

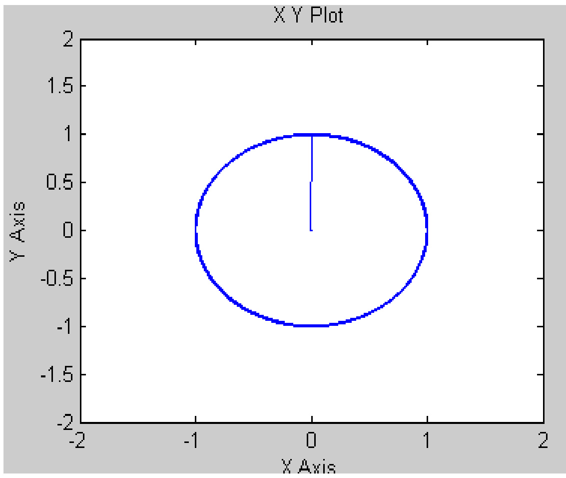
Fig.11(a),11(b) and 11(c) shows the simulation results good dynamic speed response is obtained from nine -level inverter compared to 5-7 levels DTC induction motor drive. Fig.12(a),12(b) and 12(c) shows that torque response of 5-7-9-levels inverters fed DTC, from simulation results nine level inverter fed DTC has lower ripples as compared to the 5-7 level inverter fed DTC. Fig. 13 (a), 13(b) and 13(c) Stator flux magnitudes of five , Seven and nine-level inverters. Fig. 14 (a) ,14 (b) and 14(c) source voltages of five, seven and nine-level inverters fed DTC induction motor drive.



(A)



(B)



(C)

Fig.7. Stator Flux Locus .(a) Five-level DTC (b) Seven-level DTC (c) Nine-level DTC

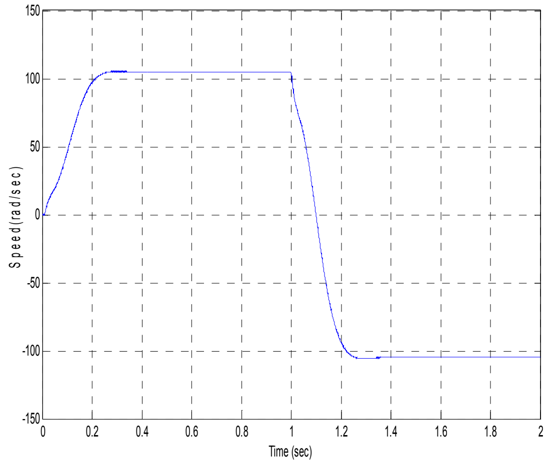


Fig.8. (a) Speed response of 5-level inverter DTC IM drive

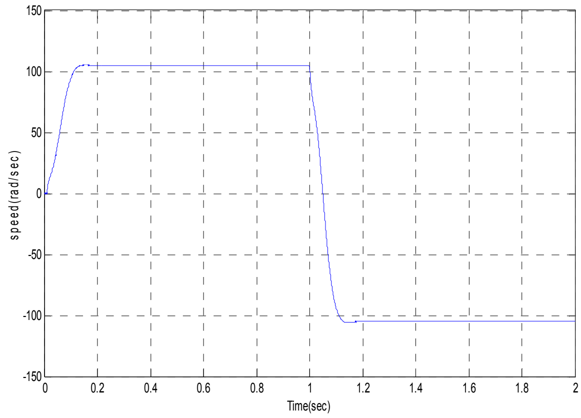


Fig.8. (b) Speed response of 7-level inverter DTC IM drive

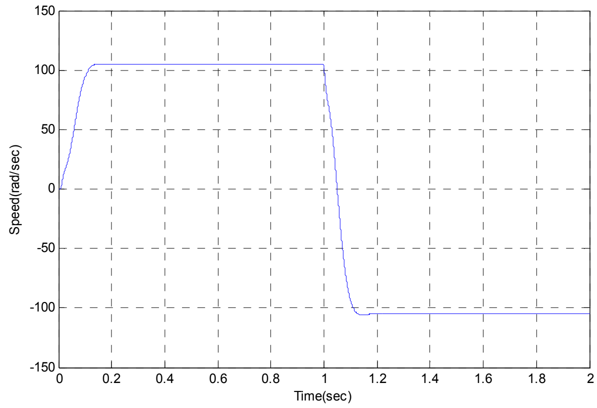


Fig.8. (c) Speed response of 9-level inverter DTC IM drive

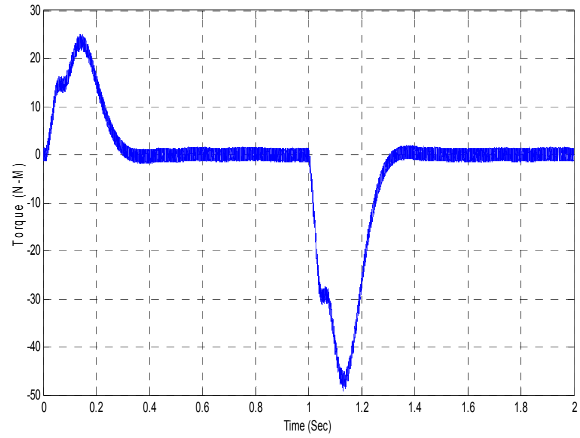


Fig.9. (a) Torque response of 5-level inverter fed DTC IM drive

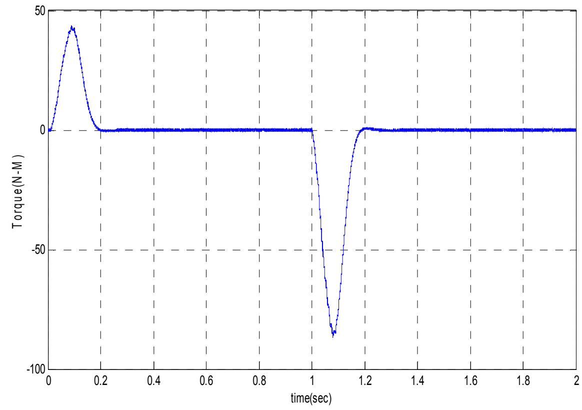


Fig.9.. (b) Torque response of 7-level inverter fed DTC IM drive

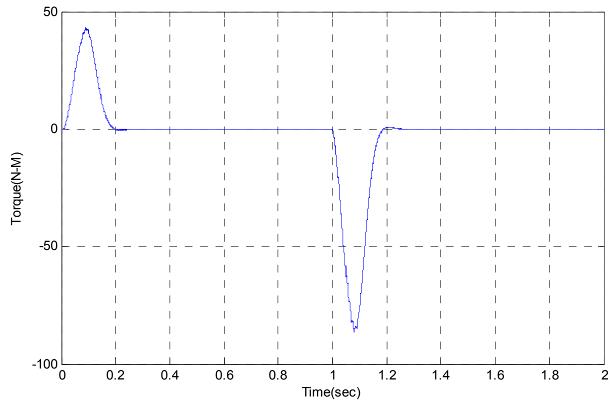


Fig.9.. (c) Torque response of 9-level inverter fed DTC IM drive

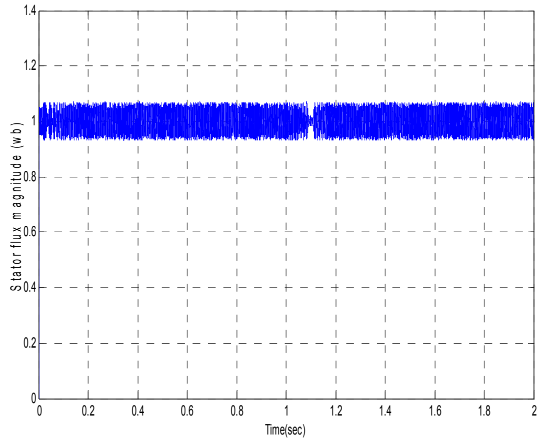


Fig.10. (a) Stator flux magnitude of 5-level inverter Fed DTC IM drive

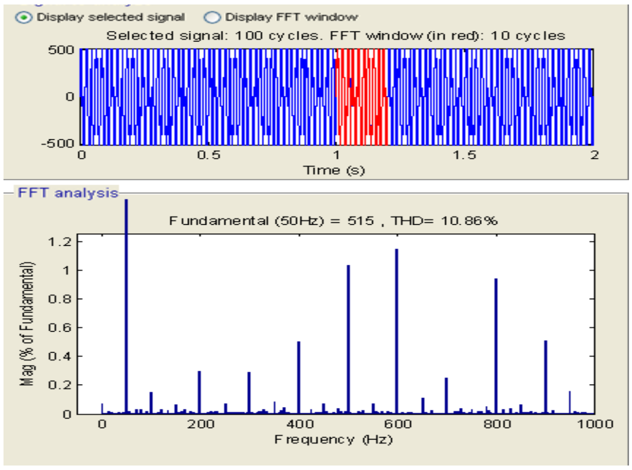


Fig.11. (a). Source line voltage of 5-level inverter fed DTC IM drive.

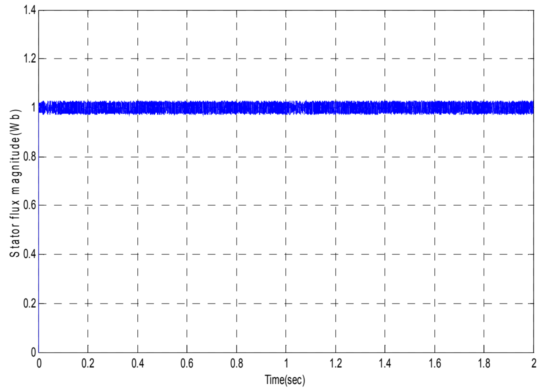


Fig.10.(b). Stator flux magnitude of 7-level inverter fed DTC IM drive

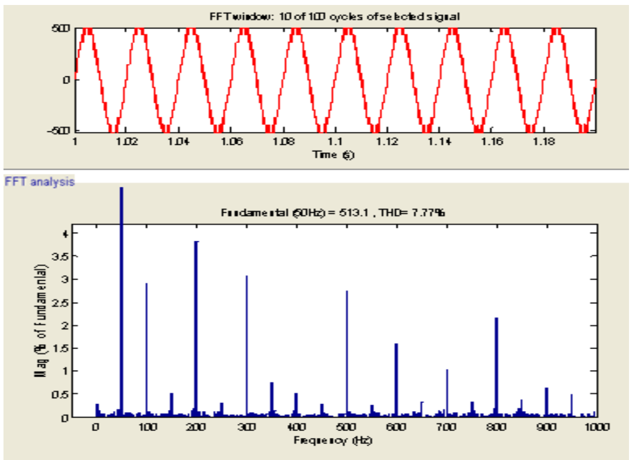


Fig.11. (b). Source line voltage of 7-level inverter fed DTC IM drive

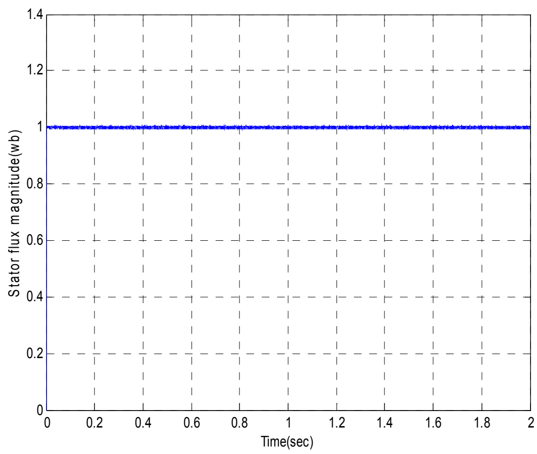


Fig.10 (c) Stator flux magnitude of 9-level inverter fed DTC IM drive

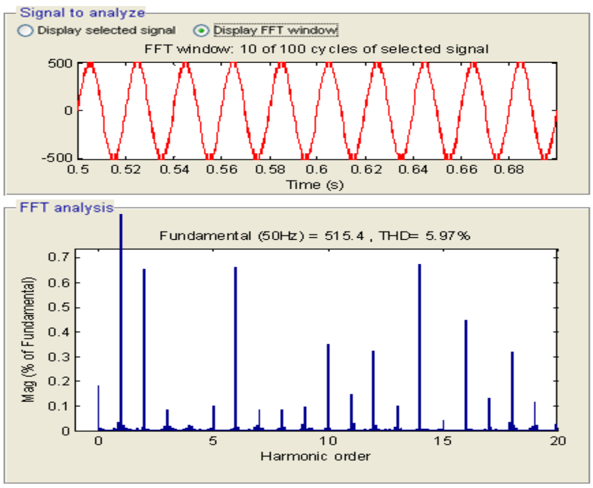


Fig.11. (c). Source line voltage of 9-level inverter fed DTC IM drive

Besides controlling the electromagnetic torque, DTC also controls the stator flux, whose locus is shown in Fig.10. The trajectory is nearly a circle and answers more quickly. As can be seen in Fig.11, the system behavior is good, even in extreme conditions like the reverse speed reference with nominal load torque applied. Reduction in ripple is observed in both electromagnetic torque and flux is due to the use of hysteresis controllers.

Table VII Comparison of Results Between 5-level, 7-Level and 9-Level Inverter Fed DTC IM Drive.

Parameters	DTC using five-level Inverter fed IM Drive	DTC using seven-level inverter fed IM Drive	DTC using Nine-level inverter fed IM Drive
Source voltage (T.H.D)	10.85%	7.77%	5.97%
Dynamic speed response time(sec)	1.22	1.12	1.01
Torque ripple(N-M)	3	1	0
Stator flux ripple(web)	≈1.13	≈1	1(ripple free)

From the above simulation results we can form the Comparison table VII,the proposed nine level inverter fed DTC drive has good dynamic speed response ,almost torque ripple is zero, stator flux ripple is significantly reduced compared to the five and seven level inverter fed DTC induction motor drive.

6. CONCLUSIONS

In this paper, a new switching table for DTC of the nine- level inverter fed DTC induction motor is proposed after the detailed case study on the characteristic of DTC and output vector of the nine-level inverter. The proposed control strategy is able to provide the required voltage levels by the system. Simulation results have shown the potential advantages of using a multilevel inverter and a DTC strategy. Advantage like flux and torque quality improvements in nine-level was found when compared with the 5-level and 7-level inverter fed DTC induction motor drive. The salient features of this proposed scheme are:

- The 9-level inverter offers improved the motor line-to-line voltage with low harmonic distortions than 5-level and 7-level inverter topologies.
- As the number of levels increased the %THD in the motor phase voltage decreased,.
- The number of level increased the torque ripple is reduced to minimum and the stator flux ripple is also minimized.
- For the proposed system has stator flux trajectory response is a circle and answer the response is faster than the 5-level and 7-level inverter fed DTC induction motor drive.

The proposed inverter system does not experience neutral-point fluctuations and the DC–link capacitor carry only the ripple current as isolated DC supplies are used for the DC links.

REFERENCES

[1] M. F. Escalante, J-C. Vannier and A. Arzandé,Flying Capacitor Multilevel Inverters and DTC Motor Drive Applications, IEEE Trans. On Industrial Electronics, vol. 49, (No.4), pp. 809-815, 2002.

[2] J. Rodriquez, J-S Lai and F. Z. Peng, Multilevel Inverters: A survey of topologies, controls, and applications, IEEE Trans. On Industrial Electronics, vol. 49, (No.4), 2002.

[3] I. Takahashi and T. Nogushi, A new quick-response and high efficiency control strategy of induction motor, IEEE Trans. On. IA, vol. 22, (No.5), pp. 820-827, 1986.

[4] G. Buja, D. Casadei and G. Serra,Direct torque control of induction motor drives, Proc. IEEE International Symposium on Industrial Electronics, vol. 1, pp.TU2-TU8, 1997.

[5] P. Vas, Sensor less Vector and Direct Torque Control. Oxford, U.K.: Oxford Univ. Press, 1998.

[6] D. Casadei, G. Grandi, G. Serra and A. Tani, Switching strategies in direct torque control of induction machines, ICEM 94, Vol. 2, pp. 204-209, 1994.

[7] I. Messaïf, E.M. Berkouk, N. Saadia and A. Talha, Application of Direct Torque Control Scheme for Induction Motor, International AMSE Conference MS'05, 2005.

[8] I. Messaïf, E.M. Berkouk, N. Saadia, Ripple Reduction in DTC Drives by Using a Three-Level NPC VSI, 14th IEEE International Conference on Electronics, Circuits and Systems, Morocco, ICECS2007.

[9] I. Messaïf, E.M. Berkouk, N. Saadia, An Improved DTC strategy for induction machine control fed by a multilevel voltage source inverter, IEEE International Conference on Electronics, Circuits and Systems, Morocco.

[10] B. P. McGrath,D.G. Holmes and T.A. Lipo,Optimised Space Vector Switching Sequences for Multilevel Inverters , IEEE Transactions on Power Electronics, Volume: 18 Issue:6,pp 1293 – 1301,2003.

TABLE IV Switching Table

		S											
C_Φ	C_Γ	1	2	3	4	5	6	7	8	9	10	11	12
	-6	304	314	305	316	300	306	301	308	302	310	303	312
	-5	224	234	225	236	220	226	221	228	222	230	223	232
	-4	104	114	105	116	100	106	101	108	102	110	103	112
	-3	67	83	68	85	63	75	64	77	65	79	66	81
	-2	117	209	118	210	113	205	114	206	125	207	116	208
	-1	5	48	6	49	1	44	2	45	3	46	4	47
	0	Zero Vector											
	+1	3	46	4	47	5	48	6	49	1	44	2	45
	+2	115	207	116	208	117	209	118	210	113	205	114	206
-1	+3	65	79	66	81	67	83	68	85	63	75	64	77
	+4	102	110	103	112	104	114	105	116	100	106	101	108
	+5	220	228	221	230	222	232	223	234	218	224	219	226
	+6	298	306	299	308	300	310	301	312	296	302	297	304
	-6	300	306	301	308	302	310	303	312	304	314	305	316
	-5	226	221	228	222	230	223	232	224	234	225	236	220
	-4	101	108	102	110	103	112	104	114	105	116	100	106
	-3	77	65	79	66	81	67	83	68	85	63	75	64
	-2	207	116	208	117	209	118	210	113	205	114	206	115
	-1	48	6	49	1	44	2	45	3	46	4	47	5
	0	Zero Vector											
	+1	45	3	46	4	47	5	48	6	49	1	44	2
+1	+2	208	117	209	118	210	113	205	114	206	115	207	116
	+3	67	84	68	86	63	76	64	78	65	80	66	82
	+4	115	105	117	100	107	101	109	102	111	103	113	104
	+5	223	235	218	225	219	227	220	229	221	231	222	233
	+6	313	296	303	297	305	298	307	299	309	300	311	301
	-6	305	316	300	306	301	308	302	310	303	312	304	314
	-5	225	236	220	226	221	228	222	230	223	232	224	234
	-4	105	116	100	106	101	108	102	110	103	112	104	114
	-3	68	85	63	75	64	77	65	79	66	81	67	83
	-2	210	113	205	114	206	115	207	116	208	117	209	118
	-1	49	1	44	2	45	3	46	4	47	5	48	6
	0	Zero Vector											
	+1	44	2	45	3	46	4	47	5	48	6	49	1
	+2	205	114	206	115	207	116	208	117	209	118	210	113
0	+3	76	64	78	65	80	66	82	67	84	68	86	63
	+4	107	101	109	102	111	103	113	104	115	105	117	100
	+5	225	219	227	220	229	221	231	222	233	223	235	218
	+6	303	297	305	298	307	299	309	300	311	301	313	296

TABLE VI Proposed Switching Table

		S											
C_Φ	C_Γ	1	2	3	4	5	6	7	8	9	10	11	12
	-8	684	694	685	696	680	686	681	688	682	690	683	692
	-7	594	604	595	606	590	596	591	598	592	600	593	602
	-6	494	504	495	506	490	496	491	498	492	500	493	502
	-5	254	264	255	266	250	256	251	258	252	260	253	262
	-4	184	194	185	196	180	186	181	188	182	190	183	192
	-3	127	143	128	145	123	135	124	137	125	139	126	141
	-2	307	399	308	400	303	395	304	396	315	397	306	398
	-1	5	48	6	49	1	44	2	45	3	46	4	47
	0	Zero Vector											
	+1	3	46	4	47	5	48	6	49	1	44	2	45
+1	+2	305	397	306	398	307	399	308	400	303	395	304	396
	+3	125	139	126	141	127	143	128	145	123	135	124	137
	+4	182	190	183	192	184	194	185	196	180	186	181	188
	+5	252	260	253	262	254	264	255	266	250	256	251	258
	+6	490	498	491	500	492	502	493	504	488	494	489	496
	7	590	598	591	600	592	602	593	604	588	594	589	596
	8	678	686	679	688	680	690	681	692	676	682	677	684
	-8	696	680	686	681	688	682	690	683	692	684	694	685
	-7	590	596	591	598	592	600	593	602	594	604	595	606
	-6	496	491	498	492	500	493	502	494	504	495	506	490
	-5	251	258	252	260	253	262	254	264	255	266	250	256
	-4	188	182	190	183	192	184	194	185	196	180	186	181
	-3	125	139	126	141	127	143	128	145	123	135	124	137
	-2	397	306	398	307	399	308	400	303	395	304	396	315
	-1	4	47	5	48	6	49	1	44	2	45	3	46
	0	Zero Vector											
	+1	45	3	46	4	47	5	48	6	49	1	44	2
-1	+2	397	306	398	307	399	308	400	303	395	304	396	305
	+3	139	126	141	127	143	128	145	123	135	124	137	125
	+4	183	192	184	194	185	196	180	186	181	188	182	190
	+5	262	254	264	255	266	250	256	251	258	252	260	253
	+6	492	502	493	504	488	494	489	496	490	498	491	500
	+7	602	593	604	588	594	589	596	590	598	591	600	592
	+8	681	692	676	682	677	684	678	686	679	688	680	690
	-8	692	684	694	685	696	680	686	681	688	682	690	683
	-7	604	595	606	590	596	591	598	592	600	593	602	594
	-6	506	490	496	491	498	492	500	493	502	494	504	495
	-5	256	251	258	252	260	253	262	254	264	255	266	250
	-4	188	182	190	183	192	184	194	185	196	180	186	181
	-3	139	126	141	127	143	128	145	123	135	124	137	125
	-2	398	307	399	308	400	303	395	304	396	315	397	306
	-1	48	6	49	1	44	2	45	3	46	4	47	5
	0	Zero Vector											
	+1	47	5	48	6	49	1	44	2	45	3	46	4
0	+2	308	400	303	395	304	396	305	397	306	398	307	399
	+3	145	123	135	124	137	125	139	126	141	127	143	128
	+4	186	181	188	182	190	183	192	184	194	185	196	180
	+5	258	252	260	253	262	254	264	255	266	250	256	251
	+6	498	491	500	492	502	493	504	488	494	489	496	490
	+7	600	592	602	593	604	588	594	589	596	590	598	591
	+8	690	681	692	676	682	677	684	678	686	679	688	680